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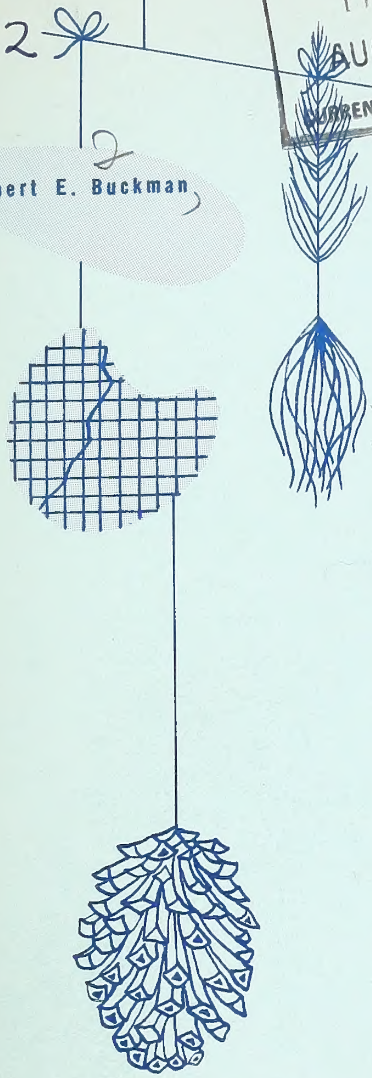
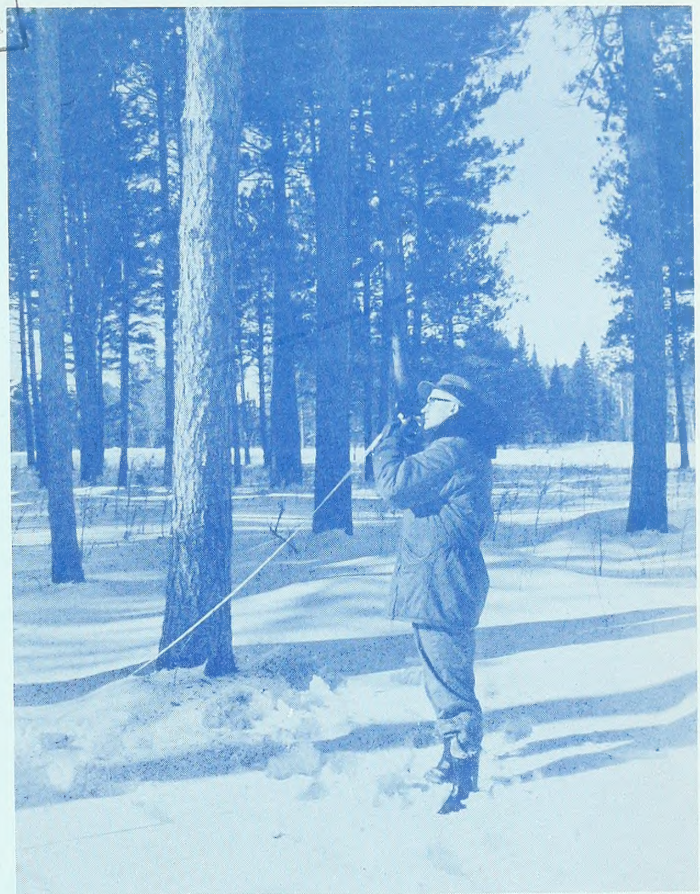
Robert E. Buckman





Three Growing-Stock Density Experiments in Minnesota Red Pine

A PROGRESS REPORT

LAKE STATES FOREST EXPERIMENT STATION
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ABSTRACT

Buckman, Robert E.

1962. Three growing-stock density experiments in Minnesota red pine: A progress report. U.S. Forest Serv., Lake States Forest Expt. Sta., Sta. Paper 99, 10 pp., illus.

Two growing-stock density experiments, one in 80-year red pine, the other in 40-year red pine, have been followed for 10 years. The third experiment, in 50-year red pine, has been followed for 5 years. Basal area growth is only slightly influenced by stand densities from 60 to 140 square feet of basal area per acre. Total height growth is not affected at all by this range of stand densities. Total cubic-foot volume and cordwood growth increase as density increases, with the increase most pronounced in the younger stands. Diameter growth of dominant and codominant trees is twice as much at 60 square feet of basal area as at 140 square feet.

Cover Picture — Research worker uses altimeter to measure heights of trees in experimental stand of red pine.

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Three Growing-Stock Density Experiments In Minnesota Red Pine: A Progress Report

by
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Introduction

Growing-stock density has been regarded as a critical question for years, wherever forestry is practiced. Indeed, most thinning experiments are designed to determine how much growing stock should remain or how much should be cut.

There is little doubt about the importance of growing-stock density to the silviculture and economics of a managed timber type. Once the stand is established, density is the one characteristic most easily controlled by the forest manager. Through manipulation of density the forest manager can, to a large extent, control the size of trees and the timing of financial returns. To a lesser extent he can control growth rates of stands and quality characteristics of the trees.

This report will examine principally the question of growth in relation to stand density. A prediction of this relationship, as well as that of growth to age and site, is being treated in a separate paper.[3]

The Experiments

This report describes three growing-stock density experiments in natural stands of red pine (*Pinus resinosa*) in Minnesota. The three experiments have the common density levels of 60, 80, 100, 120, and 140 square feet of basal area per acre. Each 5 years, the experiments are measured and the plots and surrounding buffer zones cut back to the assigned densities.

The experiments are in relatively pure, even-aged red pine. Site quality varies but little between the three stands. Beyond these common elements the experiments differ somewhat in design and detail. As will be evident in the 5- and 10-year results, there are several important similarities in the growth responses of these experiments — similarities that are highly useful in the management of red pine. The experiments are described as follows:

80-Year-Old Red Pine Density Study.

This stand is located on the Cutfoot Experimental Forest in north-central Minnesota (fig. 1). It originated about 1870 on an area burned over a few years previously. Site quality is medium; dominant and codominant trees average 50 feet at 50 years. The timber was about 80 years old when the experiment was started.

Two replications of the experiment were installed in 1949 and the third in 1950. The study was remeasured at ages 85 and 90. Following each measurement, workers cut back the plots and surrounding isolation zone to the assigned basal area. Measurements are made on three 1/5-acre plots within each density compartment.

40-Year-Old Red Pine Density Study.

This stand, also on the Cutfoot Experimental Forest, originated after a fire about 1910. Site index is medium (48 feet at 50 years).

Each density level in this experiment is represented by a single large compartment. Within each compartment there are four to nine 1/5-acre plots. This experiment has no true replication.

The original measurements were made in 1949 when the stand averaged 39 years of age. One growing season elapsed before the stand was cut to the assigned density levels.

The stand was remeasured and cut six growing

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[2] *Maintained by the Forest Service, U.S. Department of Agriculture at St. Paul 1, Minn., in cooperation with the University of Minnesota.*

[3] *Buckman, Robert E. Growth and yield of red pine in Minnesota. Manuscript being prepared for publication as a U.S. Department of Agriculture technical bulletin.*

FIGURE 1. — Basal area density of 120 square feet per acre in red pine now 90 years old.

FIGURE 2. — Basal area density of 80 square feet per acre in red pine now 55 years old.

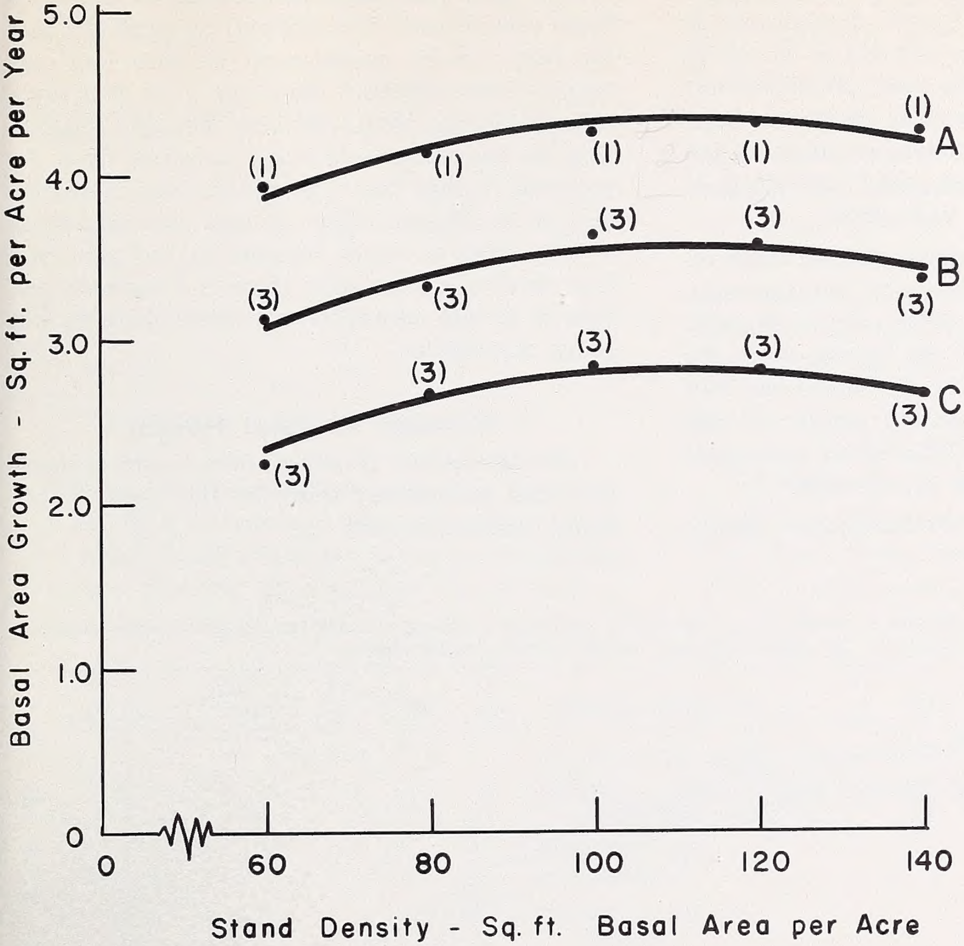

FIGURE 3. — Basal area growth of three red pine growing-stock density experiments in Minnesota. Stand A, 40-year red pine; Stand B, 50-year red pine; Stand C, 80-year red pine. Figures in parentheses indicate number of observations for each experiment.

seasons after the initial measurements were taken (five growing seasons after the first cutting). Five years later, at age 50, the stand was remeasured a second time.

50-Year-Old Red Pine Density Study.

This experiment was installed in 1955. It is commonly called the Portage Lake plots and is located on the Bena District of the Chippewa National Forest, about 25 miles southwest of the Cutfoot Experimental Forest (fig. 2). Site index is slightly better than medium (55 feet at 50 years).

The plots are arranged in a randomized block design with three replications of each density. This experiment has been observed for one 5-year measurement period. Measurements are made on a single 1/10-acre plot within each density compartment.

Two large trees died — one on a plot cut to 80 square feet of basal area, the other on a plot cut to 120 square feet of basal area. Because the plots were only 1/10 acre in size, this loss was an appreciable proportion of the plot volume. The cause of death of these trees was not apparent, but did not seem related to stand density. No deductions are made for this mortality in the ensuing analysis; the trees were considered harvested in the cutting that took place at the end of 5 years.

With the exception of these two plots, all of the information subsequently presented for the three experiments is net growth. There was little or no mortality in any of the other plots, however.

Basal Area Growth

Basal area growth for the three experiments can be represented by shallow curves or parabolas (fig. 3). The maximum growth for all three experiments occurs in the range of 100 to 120 square

feet of basal area stand density. Even then, when this maximum basal area growth is compared to that at 80 square feet on the low end of the curves or 140 square feet on the high end, the differences are small. At 60 square feet the decline in basal area growth from the maximum is about 17 per cent in the 80-year red pine stand, and about 11 percent in the 40-year red pine stand.

The basal area growth curves for the three experiments are similar in shape. In fact, the equations fitted to these points differ only in the term that controls the height of the curves above the X or stand density axis (Table 1). Notice also how closely the curves fit the plotted points for each of the three experiments. This is an agreement rarely found in silvicultural experiments.

Care must be used in generalizing about growth rates beyond the range of densities contained in these experiments. It is evident, for example, that the three growth curves must in some way converge as they approach the origin. Also, it is probable that curves would not bear the same relationship to one another if stand densities were appreciably higher than 140 square feet. Nevertheless, 60 to 140 square feet of basal area represents a wide range of stand densities in red pine, and it is helpful to know that there is a common pattern of growth between these three stands in this range of densities.

Growth in Total Height

Periodic annual growth in total height of dominant and codominant trees for the three experiments is given in table 2.

TABLE 1. — *Equation for prediction of basal area, cubic-foot volume, and 10-year diameter growth from stand density (X) for three red pine stand density experiments*

Experiment	Prediction equation	R^2 *	SE est. **
	Basal Area Growth:		
40-year red pine	$\Delta BA = 1.998 + .04225X - .000190X^2$	.91	.02
50-year red pine	$= 1.216 + .04225X - .000190X^2$		
80-year red pine	$= 0.464 + .04225X - .000190X^2$		
	Cubic-Foot Volume Growth:		
40-year red pine	$\Delta Cu.\ ft. = 40.9 + 1.3225X - .004625X^2$	.96	.73
50-year red pine	$= 36.5 + 1.3225X - .004625X^2$		
80-year red pine	$= 11.1 + 1.3225X - .004625X^2$		
	Ten-year Diameter Growth, 100 Largest Trees:		
40-year red pine	$\Delta D_{100} = 2.92 - .0119X$	.95	.023
50-year red pine	$= 2.85 - .0119X$		
80-year red pine	$= 2.67 - .0119X$		
	Ten-year Diameter Growth, Dominant and Codominant Trees:		
40-year red pine, 50-year red pine, 80-year red pine	$\Delta D_{c+d} = 2.77 - .0122X$	.91	.030

* R^2 *measures the proportion or percent of variability within studies accounted for by stand density.*

** SE *est. is the standard error of estimate. This measures the interval in which the true population mean is likely to be found (at 95-percent confidence level).*

Table 2. — *Periodic annual growth in total height in relation to stand density for three red pine experiments in Minnesota*

Density (sq. ft. basal area per acre)	Experiment		
	40-year red pine	50-year red pine	80-year red pine[1]
	Feet	*Feet*	*Feet*
60	0.98	0.84	0.36
80	.94	.82	.37
100	.99	.86	.54
120	1.05	.96	.35
140	.94	.86	.45
Average	.98	.87	.42

[1] *Heights measured on replication III only.*

Within each experiment, statistical tests did not detect a relationship between height growth and stand density. Forestry literature concerning the pines supports the conclusion that no such relationship exists except possibly on adverse sites or in extremely open or dense stands.

Not surprisingly, height growth is conspicuously slower in the older stands. The 80-year red pine in particular has less than half the annual total height growth recorded in either of the other two experiments. The fact that periodic annual height growth is little affected by density but declines, apparently in response to age, has an important effect on total cubic volume growth. This will be discussed in the next section.

Cubic Volume Growth

Mathematical curves fitted to total cubic-foot volume growth data are plotted in figure 4. As with basal area growth, the same general parabola fits all three experiments (table 1). In contrast to basal

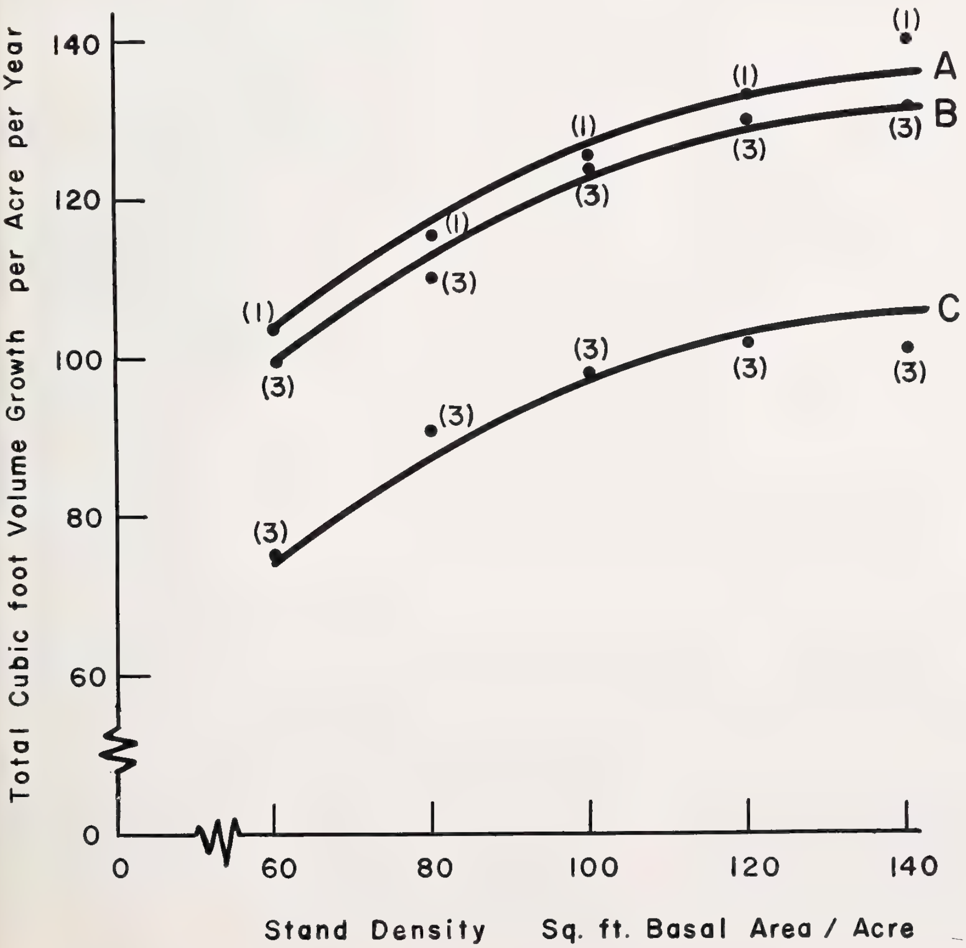

Figure 4. — Total cubic-foot volume growth of three red pine growing stock density experiments in Minnesota. Stand A, 40-year red pine; Stand B, 50-year red pine; Stand C, 80-year red pine. Figures in parentheses indicate number of observations for each experiment.

area growth, however, cubic volume growth continues to rise as density increases.[4]

This apparent increase of total cubic volume growth with increasing density deserves careful study because: (1) it has important forest management implications, and (2) it represents a modification or extension of the currently popular theory that total cubic volume growth is little changed over a wide range of stand densities. Let us examine the second item first.

An argument advanced by Wiedemann (1950) and described in English by Braathe (1957) furnishes a mathematical explanation as to where (but not why) the cubic volume growth is added to the higher density stands. In words rather than algebraic symbols the argument adopts itself to the present studies like this:

1. Total cubic-foot volume growth is made up of increases in stand basal area, stand height, and tree form (ignored for the present).
2. Basal area growth is little affected by density (see fig. 3).
3. Total height growth is unchanged by density (table 2).
4. Therefore, total cubic-volume growth is greater in stands of high density because there are more stems (or correctly, more basal area) upon which to add height growth. This effect becomes more pronounced in stands that are growing rapidly in height.

This rather involved argument is illustrated in figure 5 with actual observations from the 40-year red pine study. The difference in volume growth between the 80- and 140-square-foot densities is shown as a cross-hatched area.

Tree form, or the relative fullness of the boles, is ignored in this analysis except as the underlying volume tables reflect form. However, it would seem that tree form should operate in a direction to further support the above argument. Trees in dense stands would have relatively less taper, hence would produce more wood in the upper stems for each square foot of basal area growth

[4] *In curve fitting, the three experiments were treated as if they came from a common population of red pine. Variation was first removed between experiments, and then curves were fitted to account for as much as possible of the remaining variation.*

So much variation was removed by the cubic-foot volume curves (R^2 = .96) that there was little justification for using a separate equation for stands A and C (fig. 4), even though there is a suggestion from the plotted points that a different curve might be appropriate. There are some logical grounds for believing that the departure of the observed points from the upper ends of curves A and C is real. If so, this would be detected by statistical tests if density levels were still higher, or if there were more replications within the experiments (see later text).

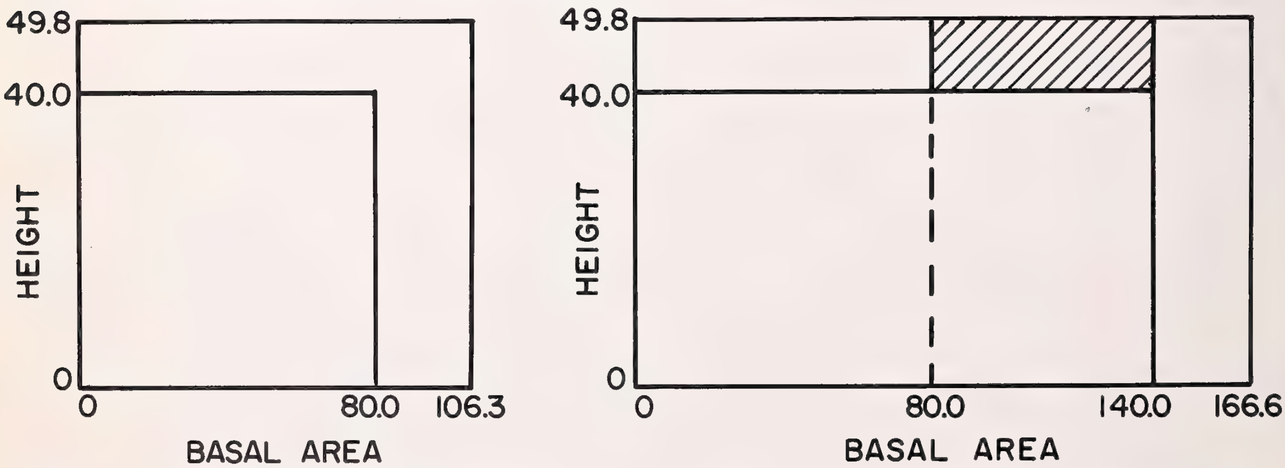

FIGURE 5. — An illustration of volume growth using actual data from the 40-year density study. On the left is the stand with 80 square feet of basal area and 40 feet average total height of dominants and codominants. On the right is the stand with 140 square feet of basal area and 40 feet total height. The 80-square-foot stand grew 26.3 square feet of basal area in 10 years, the 140-square-foot stand grew 26.6 square feet in the same time. The 10-year height increase in both stands was 9.8 feet. Both stands grew practically the same in basal area, and the same in height, but volume growth is greater in the 140-square-foot stand. The difference in volume growth is due mainly to the greater basal area upon which height growth was added. This difference is cross-hatched on the figure above.

as measured at breast height. Additional work is needed to assess the importance of changes in tree form to volume growth.

Although statistical tests do not detect it, the plotted points in figure 4 suggest a somewhat different curve form for the 40-year-old and 80-year-old red pine studies (Stands A and C respectively). It appears that the plotted points are still rising in the 40-year timber at high densities, but have leveled off at the 120- and 140-square-foot densities in the 80-year timber. The argument of Wiedemann and Braathe again provides an explanation for the apparent continued rise in the young stand and leveling off in the older stand. Height growth in young stands is rapid and a very important component of volume growth. In this situation volume growth tends to be greater in higher density stands, for the reasons discussed above. In older stands height growth is much lower (see table 2), and therefore relatively less important as a component of volume growth. As height growth becomes less important the volume growth of the stand tends to be more strongly influenced by the basal area component, which itself is not markedly affected by density. Thus, as stands get older, the upward trend of the volume curve at higher densities diminishes and eventually levels off.

In addition to the evidence given in figure 4, other recent research papers indicate that, up to a point, cubic volume growth of several species of *Pinus* increases with density. Among these papers are: Hiley (1959) who describes conifer plantations in South Africa; Brender (1960) working with loblolly pine in the Piedmont area of the South; Smithers (1954) dealing with thinning plots in red and white pine in Ontario; Gruschow and Evans (1959) working with slash pine in the Southeast; and Williams (1959) studying shortleaf pine plantations in Indiana.

One characteristic describes the stands analyzed in the above papers: They are relatively young and presumably have rapid height growth. This characteristic describes the 40-year and 50-year red pine studies also. Three of the experiments (Brender, Smithers, and Williams) provide sufficient information about basal area and height growth to support in principle the argument of Wiedemann and Braathe as it applies to the present three studies.

This observation — that cubic-volume growth increases with density — is in conflict with what is sometimes referred to as the Möller theory (Möller 1954). This theory states that stands from about 50 percent to 100 percent of full stocking show little difference in volume growth. However, the conflict applies only to stands where height growth is making an important contribution to volume increment. It seems likely that many studies in older stands still support the Möller contention.

In the final analysis it may not be important to the forest manager that he get somewhat higher cubic-volume growth in young stands. He may be more interested in manipulating stand density to obtain larger trees or earlier financial returns than would be possible in high density stands. But if the forest manager seeks maximum production of red pine fiber, the evidence presented here argues for high density management in red pine stands. Unfortunately the red pine experiments described in this paper do not cover a wide enough range to show the point where cubic volume growth drops off because of excessively high density.

Merchantable Volume Growth

Table 3 describes the merchantable volume growth in board feet for 80-year red pine, and in cordwood for 40- and 50-year studies. These are the products that would be derived from each of the stands if they were cut today.

Notice how cordwood growth tends to increase with density. This is much the pattern traced by cubic volume growth in figure 4. Board-foot growth departs slightly from the cubic volume growth pattern because of substantial ingrowth into

TABLE 3. — *Periodic annual cordwood or board-foot growth in relation to stand density for three red pine experiments in Minnesota*

Density (sq. ft. basal area per acre)	Experiment		
	40-year red pine	50-year red pine	80-year red pine
	Cordwood[1]	*Cordwood*[1]	*Board feet*[1]
60	1.05	1.00	440
80	1.15	1.12	520
100	1.33	1.26	580
120	1.34	1.32	680
140	1.42	1.32	620

1 *Cordwood includes unpeeled volume of all trees 3.6 inches d.b.h. to 3.0inch top d.i.b. Board feet includes volume Scribner Decimal C. log rule of all trees 7.6 inches d.b.h. to a 6.0-inch top d.i.b.*

board-foot diameter classes. This departure is dependent upon utilization standards, stand history, and stand age.

Table 3 illustrates the problem of predicting merchantable growth in relation to stand density. Where the ingrowth period is essentially past, as it is with cordwood, a pattern similar to cubic-volume growth develops. Given a few years, the board-foot growth pattern obtained from new measurements will behave much like cubic-volume growth.

Diameter Growth

Diameter is the main tree characteristic altered by different densities. Since there is relatively little change in basal area growth at any of the selected densities (fig. 3), it follows that this growth will be distributed over few trees in the lower density stands and more trees in higher density stands.

Figure 6 shows the 10-year diameter growth per acre of the 100 largest trees in each of the three stands. Lines A, B, and C, representing the three experiments, have the same slope but the trees in the younger stands have more rapid diameter growth.

Line D represents the 10-year diameter growth of dominant and codominant trees for all three experiments combined, because there was no significant difference between experiments. There are fewer observations for the dominant-codominant analysis because crowns were classified on one instead of three replications of the 80-year red pine.

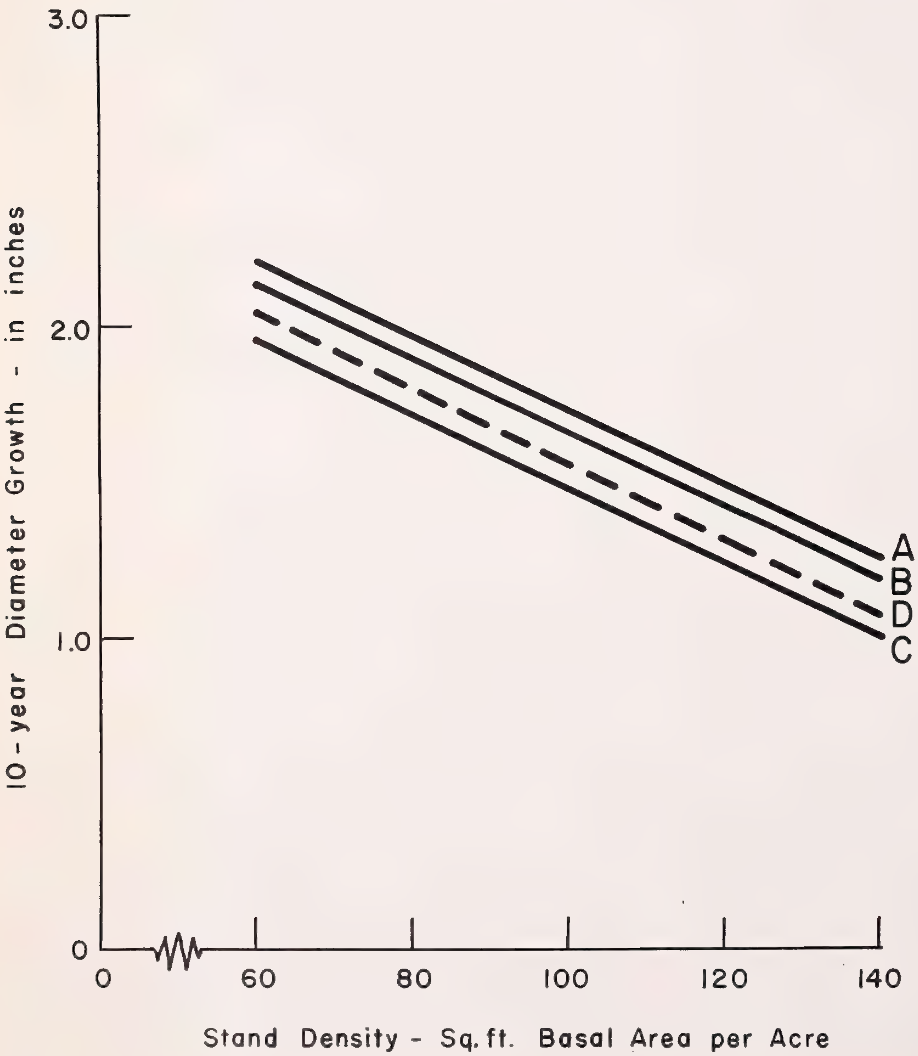

FIGURE 6. — Ten-year diameter growth of 100 largest trees per acre (solid lines) and ten-year diameter growth of dominant and codominant trees (dashed line) on three red pine growing stock density experiments in Minnesota. Stand A, 40-year red pine; Stand B, 50-year red pine; Stand C, 80-year red pine. D is a composite since there is no important difference in growth of dominants and codominants in any of the three experiments.

Nevertheless, this single regression line still accounts for 91 percent of total variation in the three experiments (table 1).

For all three experiments the 10-year diameter growth at 60 square feet basal area is about double that at 140 square feet. This is true in both the diameter growth of dominant and codominant trees and that of the 100 largest trees per acre.

Although there is some difference between experiments in diameter growth of the 100 largest trees per acre, it is slight. For example, growth only varies about 0.25 inch in 10 years at all density levels between the 80- and 40-year-old red pine. A land manager could maintain uniform diameter growth between ages 40 and 90 by gradually removing 20 sq. ft. of basal area. A series of thinning cuts would do the job.

Timber markers can use diameter growth rate information to advantage in stands of the kind described here. Suppose the marker committed to memory one or two diameter growth rates for a particular age class and density. He could then predict the trees' diameters 10 or 20 years hence. This is important in Minnesota because many premium products are derived from certain red pine diameter classes (e.g. barn or utility poles, highway guard posts, and round timber piles).

Summary

This paper describes three growing-stock density studies in Minnesota red pine. Although the studies differ in stand age (40, 50 and 80 years) and in details of design, they are all on medium site. Also, they all have the common densities of 60, 80, 100, 120, and 140 square feet of basal area per acre at the beginning of 5-year cutting cycles.

Basal area growth is described by three shallow curves. Between the three experiments, basal area growth differs in magnitude, but the shapes of the individual curves are practically identical.

Periodic annual height growth is unaffected by stand density. Total cubic volume growth increases with stand density, and this increase is most pronounced in the two younger stands. Since basal area growth is little affected by stand density and height growth is unchanged, higher cubic volume growth occurs in high density stands because there are more stems (or more basal area) upon which to add height growth.

Cordwood growth for the two younger stands follows the pattern of cubic volume growth, reaching 1.3 to 1.4 cords per acre per year in the 120- and 140-square-foot densities. Board-foot growth in the 80-year red pine tends to follow the pattern set by cubic volume growth although ingrowth distorts the pattern slightly.

For all three experiments, diameter growth of both the 100 largest trees per acre and the dominant and codominant trees is roughly twice as much at 60 square feet as it is at 140 square feet. Ten-year diameter growth of dominant and codominant trees does not differ significantly between the three experiments. Ten-year diameter growth of the 100 largest trees per acre averages about 0.25 inch greater in the 40-year than in the 80-year red pine study, with the 50-year red pine falling between the two.

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